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IRRIGATION STUDIES.

By ELWOOD MEAD, M. Am. Soc. C. E.

PRESENTED SEPTEMBER 5TH, 1900.

WITH DISCUSSION.

The Office of Experiment Stations of the United States Department of Agriculture is now engaged in a comprehensive study of the methods of distributing and using water in irrigation. The results of these studies for 1899 have been compiled, and will shortly be published by the Department. Some of the methods used in these investigations, and the results of the measurements to determine the losses from seepage and evaporation in canals and the duty of water utilized have been extracted from the report, and are presented in this paper.

The investigations described deal with problems which sorely perplex the irrigators and canal builders of the arid West. Their comprehensive study is a new feature of national aid to irrigation development in this country. Heretofore, the leading object of such aid has been to promote the construction of new canals, to show how much land there was above existing ditches which could be reclaimed, and the benefits which would come from such reclamation. It is believed that this investigation will tend to secure these ends, but its primary

purpose is to promote the welfare of the people living below the ditches already built, to render the farms now irrigated more profitable, to lessen the controversies over the distribution of water and secure its more systematic and economical use.

It is the opinion of those best informed that a better understanding of the existing situation must be had before we can wisely plan for future development. Controversies over the use of streams should be ended before an attempt is made to greatly augment such use. The claims to water, for existing and prospective ditches on many streams, amount in the aggregate to many times the supply. The character and extent of the rights now vested must determine what is to be done in the future. In the pioneer stages of western irrigation, the importance of these questions was lost sight of. The owners of the earlier ditches from a river did not need to consider how much water was used or how much was wasted, since neither had as yet made any serious reduction in the supply. Every transaction which had to do with the disposal of streams was marked by a lavish prodigality. Ditches diverted more water than was used; their owners claimed more than they could divert, while decrees gave appropriators titles to more water than ditches could carry and many times what the highest flood could supply. Little was known of the quantity of water needed to irrigate an acre of land, and in the absence of such information the ignorance and greed of the speculative appropriator had its opportunity.

The contracts which control the distribution of water from canals were framed by people to whom the whole subject of irrigation was strange and new. It often happens, therefore, that they do not promote the best interests of canal companies or meet the necessities of users. The laws which govern appropriations of water from streams have in most cases no relation to the actual practice of irrigators, and, therefore, fail to secure either the systematic distribution or best use of the available supply.

Before the period of crude structures and still cruder ideas had ended, it began to be manifest that the reclamation of arid lands involved more than the overcoming of physical obstacles. It has been found easier to dig ditches than to distribute the water they carry, and to plan headgates and flumes than to frame just laws for establishing titles to water or dividing rivers among rival claimants.

The many thousands of miles of canals and laterals in the irrigated regions of the United States have reclaimed an area approximately as great as the State of New York, every acre and almost every square foot of which has to be artificially moistened from one to ten times each year. During the growing season this requires the services of an army of men to protect and regulate headgates, patrol the banks of canals and adjust the measuring boxes of users. The success or failure of these canals is a matter of more than local interest. Much of the money expended in their construction came from the East. The small savings of thousands of thrifty New England people have been invested in stocks and bonds of irrigation companies, a single agency in Colorado having invested $15 000 000 in this class of securities for these customers. The failure of a canal company to find customers for the water carried, or to obtain water for the customers it has, affects many others besides the water user. His is the immediate loss, but sooner or later the holder of the stocks or bonds of the canal company finds that he, too, is suffering through delayed or defaulted interest payments. The justice and efficiency with which the stream is divided, and the economy with which the water is used, may augment or reduce the incomes of many thousands of eastern as well as western homes.

The Distribution of Water Among Users.

Traffic in water is carried on under many peculiar and perplexing conditions. No matter from what source the supply is received, whether it is stored in reservoirs, pumped from wells or taken from rivers, the distribution of water in irrigation is subject to unending uncertainties. Streams rise and fall with every passing cloud. The torrent of to-day may be a dry channel a month hence. Wells which cannot be exhausted in April are often empty in June. Even after water has passed the headgate and is safe from outside interference, the waste and loss continue. It disappears through the bottom of the canal by seepage, and into the air by evaporation. The same vicissitude attends its use. As much water may escape from the lower side of the field of a careless irrigator as sinks into the soil. The waste from badly built laterals or poorly prepared fields does much to limit the acres which a canal can serve, and hence the income it can be made to yield.

This commerce in water has been created by men born and reared in regions of ample rainfall, and without prior training or experience in dealing with the problems of irrigation. They had to learn by trial how to frame satisfactory contracts for the disposal of water from canals, and how to use that water properly when delivered. From the construction of the first small furrows in Utah and California up to the present, the growth in acres irrigated has been accompanied by an equally important evolution in methods. The fixing of a unit of measure to be used in delivering water to users will serve to illustrate this. It could not be sold by the pound or by the ton, nor were there any devices at hand for its measurement or delivery by the gallon. Farmers were at a loss to know how much to buy, and canal companies as ignorant of how much they could sell or how to measure it when sold.

The Units of Volume Used in Measuring Water.

The "Inch."—In a number of the arid states placer mining was an important industry before irrigation began. Miners, in measuring water, used the "inch." This is the volume which will flow through an inch-square orifice under a uniform and designated pressure. Later, the pressure to be used, and the manner in which the size of the orifice was to be increased or diminished, was, in a number of states, fixed by law.

"Water sold by the inch by any individual or corporation shall be measured as follows, to wit: Every inch shall be considered equal to an inch-square orifice under a 5-in. pressure, and a 5-in. pressure shall be from the top of the orifice of the box put into the banks of the ditch to the surface of the water; said boxes or any slot or aperture through which such water shall be measured shall in all cases be 6 ins., perpendicular, inside measurement, except boxes delivering less than 12 ins., which may be square, with or without slides; all slides for the same shall move horizontally, and not otherwise; and said box put into the banks of ditch shall have a descending grade from the water in ditch of not less than one-eighth of an inch to the foot."*

In those sections where irrigation succeeded this form of mining, irrigators generally adopted this unit. In many respects it is entirely satisfactory. Where the flow is controlled by a device of reasonable accuracy it is a convenient method of delivery for canal companies, and satisfactory to users, because they can tell at a glance whether or

* General Statutes of Colorado, Sec. 3472.

not the quantity contracted for is being delivered. It is not suited, however, to the measurement of rivers or to the regulation of their division among large canals, as the prescribed conditions cannot be produced on a large stream of water. There are canals which carry 125 000 ins. To measure this volume, under the conditions prescribed in the Colorado statute, would be practically impossible. The use of the term "inch" has been unfortunate. Many farmers have confused this unit with the square inch or the cubic inch, and it frequently happens that the inches of water bought or sold are determined by measuring the cross-section of a ditch or lateral, paying no attention whatever to either grade or velocity. In one case a state law confuses cubic inches with the continuous flow from an inch-square orifice.

The Cubic Foot per Second.—When it became necessary to gauge streams and to measure the volume of large canals, it was manifest that some other unit of measurement that the miner's "inch" had to be used. The cubic foot per second is the unit which has passed into general use. This unit has the double advantage of showing precisely what is meant, and being well adapted to the measurement of large as well as small volumes of flowing water. It is the most satisfactory unit which can be used in dividing rivers or in measuring the flow of large canals where the flow is continuous. There is, however, an objection to its universal use in water-right contracts, or in decrees establishing rights to water. Where decrees or contracts provide for the measurement of the quantity received as a continuous flow, it presupposes that irrigators use water in this manner. This is not in accord with the best practice. Irrigators do not need water all the time. Few use it half the time. If they are required to pay for a continuous flow, they usually pay for something they do not get, and always for what they do not need. If they are allowed, as an equivalent of a continuous flow, to take a larger volume for a shorter time, a different unit of measurement is desirable; because it is not a stream of a particular size, but the total volume received, which is paid for.

The Acre-Foot.—The growing recognition of the fact that a continuous flow of water does not correspond to the needs of irrigators has recently brought into use another unit of volume, the acre-foot. It contains 43 560 cu. ft., or enough to cover an acre 1 ft. deep. It is a convenient unit for selling stored water, because it can be used to measure the capacity of reservoirs.

Contracts in which the acre-foot is used provide for the delivery of water on the demand of the irrigator, or at intervals rather than in continuous flow; and canal companies have hesitated about adopting this unit, because of a fear that satisfactory arrangements for delivery could not be made, and that more water would be called for at some times than the canal could supply, while at other times the entire volume would run to waste.

Wherever the acre-foot has been adopted it has proven acceptable to irrigators, because they share in the benefit resulting from care and skill in distribution.

Form of Water Contracts and Benefits of Rotation.

Contracts for supplying water take many forms. In some cases they are deeds to the water delivered; in others they purport to transfer a perpetual right to a specified quantity or to a stream of a specified size; in others they agree to provide water for the irrigation of a specified number of acres for one year; while a few provide for payment for the quantity actually used, fixing a maximum quantity which may be demanded in one season. At first these contracts were largely governed by the ideas of the managers of the canals, but sufficient experience has now been had to make certain forms of contracts preferred in behalf of public as well as private interests.

Contracts which provide for the delivery of a uniform, constant flow are, as a rule, wasteful of water, and are not in the interests of either ditch companies or the public. Contracts which charge for the acres irrigated, without regard to the volume used on these acres, are a temptation to extravagance on the part of the irrigator. The canal company which adopts such contracts resembles the grocer who would agree to supply his customers with a year's provisions at so much per head, with no restrictions as to quantity or kind of goods which might be called for. On the other hand, contracts providing payment proportioned to the quantity delivered, and for delivery in amounts which can be most efficiently distributed, cannot fail to lead to economy in the use of water, and consequently to a high duty. Under such a system the irrigator is benefited by his saving, and pays for his waste. Such contracts can only be used in connection with a system of rotation in delivery to irrigators. This rotation benefits the canal company as well as the irrigator, because it lessens the loss

from evaporation and seepage. A canal 60 miles long could be divided into three sections of 20 miles each, and all the loss from seepage and evaporation on the lower 40 miles saved while the irrigators of the upper section were being supplied. In the same way, by keeping the full supply in the canal, water could be rushed through to users under the lower section with less loss than where the flow is depleted by laterals along the route. The greatest saving in rotation, however, would be made in the laterals. Where water is permitted to slowly dribble through continuously, the waste is enormous. By devising a system for grouping the laterals and inducing the irrigators therefrom to take water by turns, the engineer can do as much toward raising the duty obtained as the actual cultivator. The use of a unit which favors rotation between users leads also to rotation in the division of the river between the canals. The loss from seepage and evaporation is approximately the same whether the canals are full or only half full. When rivers are low, by running half the canals at a time with a full supply, nearly half the water ordinarily lost in transit is saved. As the loss from seepage and evaporation averages about 30% of the water flowing in canals, the water saved by such rotation is a material addition to the available supply.

Reasons for Investigation of the Duty of Water.

As the water required to irrigate 1 acre of land should be the basis for fixing the dimensions of works required to irrigate any number of acres, there is need to know approximately its amount. In order to plan for the just distribution of the volume entering the headgate, the losses in transit must be provided for. Until more is known than is now known about the time of year when the irrigation season begins and ends, the part of the discharge which must run to waste unless stored cannot be estimated. Until it is known how large an area an acre-foot of stored water will irrigate, and the returns which will come from such irrigation, the value of reservoirs will have no more substantial basis than individual judgment or conjecture, and no intelligent estimate can be made of the amount of money which can be profitably spent in their construction. Sooner or later, a knowledge of the duty of water becomes a necessity in any irrigated district. It is now urgently needed to settle disputes over water-right contracts, and to provide for their intelligent reconstruc-

tion. Thus far, it has been the uniform practice to make all rights to water perpetual and continuous. This is not the practice of European countries. Italy, France and Spain, each distinguishes clearly between rights to the summer and to the winter flow, the vernal and autumnal equinoxes being the dates when one begins and the other ends. The controversies which have recently arisen over rights to the winter flow of streams will doubtless soon lead to a similar distinction in western irrigation laws. A comparison of the duties secured under many of the canals where measurements were made last year leads to the belief that it will be possible through improved methods to double the average duty now obtained, so that the quantity now required for one acre will serve to irrigate two. If this can be accomplished it will relieve the scarcity under many canals, put an end to many controversies growing out of the existing scarcity, lessen the expense per acre for water, and increase immensely the productive and taxable resources of the arid States.

Believing that a more general understanding of the causes which increase or diminish the duty of water is one of the most urgent needs of irrigated agriculture, the determination of this duty was made a leading subject of the investigation.

Methods Used in the Investigation.

In carrying out this investigation laboratory methods will not answer; it must deal with the use of water on a large scale. The work requires the supervision of men of special training and wide practical experience. One of the chief difficulties encountered at the outset was to find the right men to take charge. Those engaged are, without exception, holding positions of responsibility and receiving ample compensation from other sources. The chief inducement for their taking part in this investigation has been the promotion of the public welfare. Through their interest and zeal a large amount of information was obtained which could not otherwise have been secured for ten times the actual outlay. It was left for the observers in each State to secure the co-operation of intelligent, practical farmers, and to arrange with them to measure the water used on their fields. In nearly every case this was easily accomplished. Every farmer connected with the investigation received the same instruction. It was, to use water whenever and wherever it was thought necessary, pro-

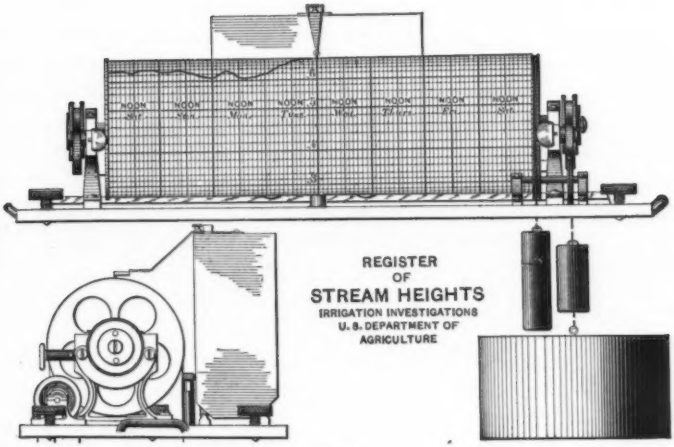
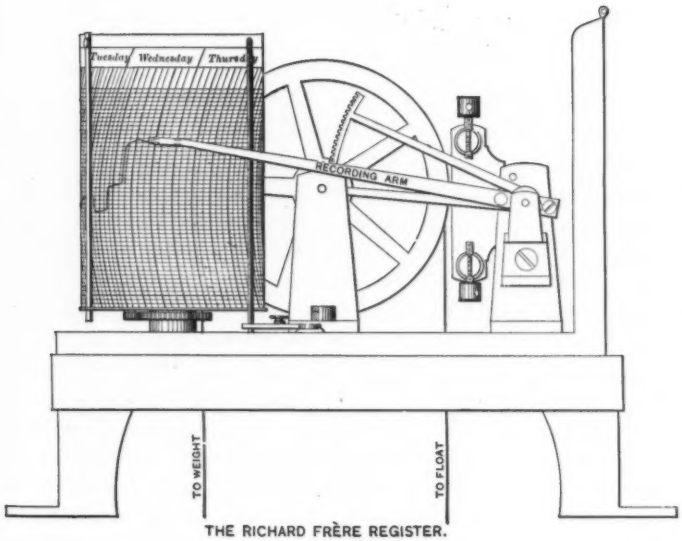


FIG. 1.



THE RICHARD FRÈRE REGISTER.

FIG. 2.

vided it could be had, and pay no attention to the fact that it was being measured. The results show that this was done. The description of canal systems and the methods which govern their operation, given in the reports of the special agents, show how direct is the relation between good management and a high duty of water. They also show how prolific of waste and loss is a badly drawn water-right contract. Records were also kept of rainfall and evaporation, and an effort was made in each case to secure as much information as possible on the following factors of the duty of water in irrigation:

The quantity of water required by different crops.

The length of the irrigation period in different sections of the arid region.

The agreement or divergence between the quantity of water used in irrigation in the different months of the growing season, and the rise and fall of streams during those months.

The benefits of reservoirs, and the percentage of the total discharge of streams which must be stored in order to utilize it all.

Losses in canals from seepage and evaporation.

Influence of different forms of water-right contracts in promoting economy or waste.

The returns from the use in irrigation of an acre-foot of water.

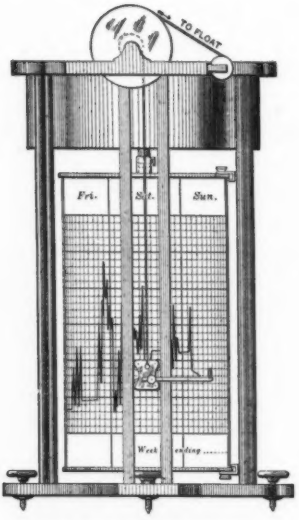
Instruments Used in Recording Amounts of Water Used.

In the study of the duty of water, and to record the quantity used, provision had to be made for an instrument which would be automatic and continuous in its operation. This was necessary because the quantity received by each irrigator from his lateral is subject to frequent change. Finding it impossible to use a meter to measure the volume delivered, it was decided to place a weir or flume in each canal or lateral, and then, by means of a suitable instrument, keep a continuous record of the depth of water delivered. Wherever possible, weirs were used, but in more than half the cases where they were used the results proved that flumes would have been more satisfactory.

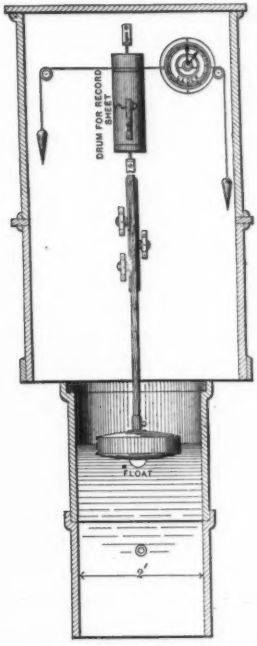
A study of the registers in use showed that none was wholly satisfactory. The first requisite was a record on a natural scale, so that an inch rise or fall in the ditch would be so shown on the record sheets, thus enabling any farmer or ditch rider to determine at a glance

whether or not the instrument was working accurately, and, if not, to correct it without the computation required where the scale is reduced. Not being able to obtain registers of this pattern, one was designed. Its form is shown in Fig. 1.

In this instrument the rise and fall of the water in a ditch or lateral raises and lowers a float and counter-weight. This float and counter-weight are connected by a cord which passes over the end of a cylinder



THE WYOMING NILOMETER
FIG. 3.



REGISTER OF HEIGHT OF WATER
GAGE CANAL, RIVERSIDE, CALIFORNIA
FIG. 4.

which is revolved by the movement of the cord as the float rises and falls with the changes of depth in the stream. This cylinder carries a paper divided into rectangular spaces, the time divisions being parallel to its axis and the depth divisions at right angles thereto. The pen or pencil making the record is moved along this cylinder by clockwork, and passes from one end to the other in a week, when the paper is

changed and the pen returned to the starting point. The only result of a wide variation in stream depth is an increase in the number of revolutions of the cylinder.

Owing to delay in the construction of these instruments, all observers could not be supplied with them, and a number of registers of other patterns were used. The Richard Frère register, Fig. 2, was utilized in the measurements in Arizona, the instruments being loaned by the University of Arizona. The Wyoming Nilometer, Fig. 3, was used at the Wyoming and Nebraska Stations. The Irving register, Fig. 4, was used on the Gage Canal in California. Plate XIII shows the method of placing registers used in weir measurements.

Relative Merits of Weirs and Flumes in the Measurement of Water.

Reference has already been made to the fact that some of the weirs did not prove satisfactory. This was due to the deposit of silt above them. Sediment investigations made during the season showed that certain southern streams carry, during floods, as high as 5% of solid matter in suspension, and that canals and laterals taking water from these streams have to be cleaned from two to three times each year. Even where the percentage was much less than this, the deposit of sediment was so rapid in some cases as to fill the lateral or ditch above the weir to a level with its crest in 24 hours. Where this happened, the velocity of approach became a disturbing factor, the influence of which could not be determined owing to the constant change of conditions. Some canal companies which use weirs, operate, in connection therewith, a sluicing device which removes the accumulated sediment once each day. The objection to this is that the conditions are never stable, and it is impossible to tell for what length of time the weir tables used agree with the actual discharge. The recent investigations in the flow of water over dams and over weirs, other than those with sharp edges, may aid in securing the adoption of a form of weir better suited to the sediment-laden waters of the Southwest than that used, but, so far as knife-edged weirs are concerned, there are few ditches in the Southwest where it is not possible to secure rating tables for flumes which will give much more reliable and accurate results. It was also found that, in the case of a number of canals, the grades were too small and the banks too low to secure the requisite fall

PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS.
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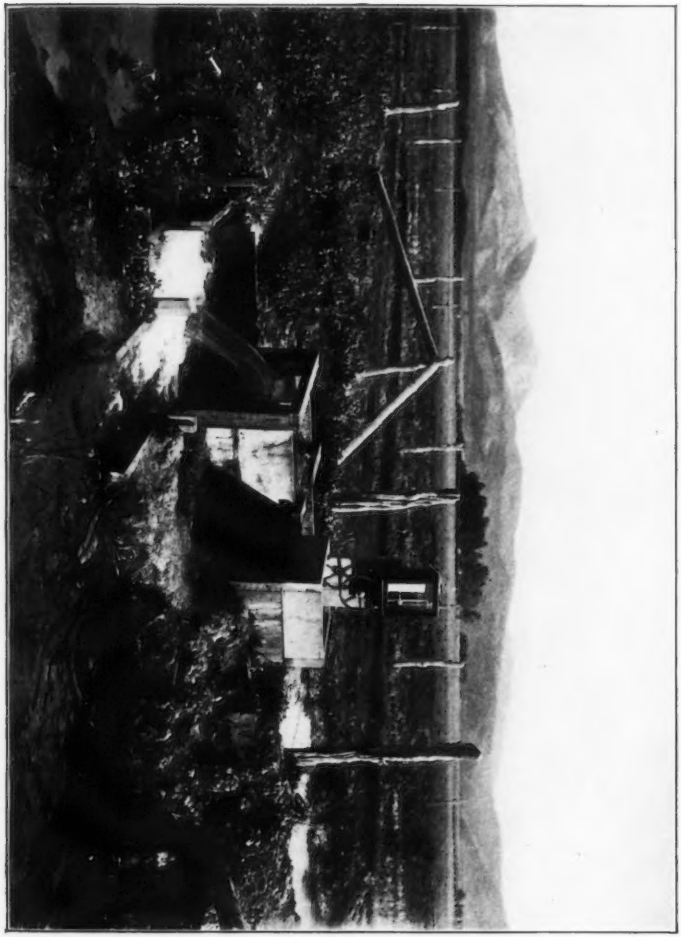
MEAD ON IRRIGATION STUDIES.



REGISTER FOR WEIR MEASUREMENTS.

below the weir, and in such cases flumes would not only be preferable but an inevitable substitute.

The most serious objection to the use of flumes is the labor of preparing an accurate rating table, and the fact that a current meter is required for doing this. The recent improvements in these instruments, by which both their convenience and accuracy have been increased, has made it a simple matter to prepare a discharge table for flumes in which the flow is reasonably uniform. With ordinary care this discharge can be determined within the limits of accuracy permitted by the meter used, and in the best instruments this error is as low as 1 per cent. This margin of error is below what is permissible in the delivery of water or attainable in this investigation. The relation of the volume discharged to the depth of water in the measuring

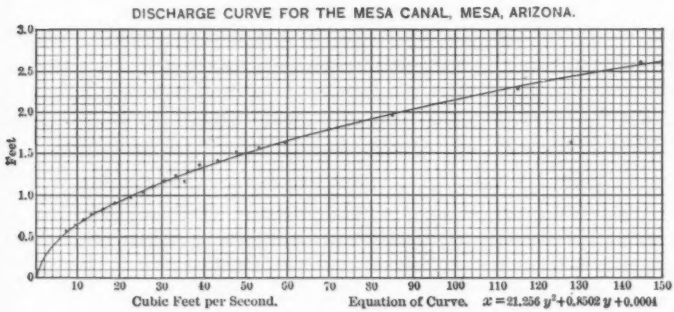


FIG. 5.

flume of the Mesa Canal, Arizona, is shown in Fig. 5. The dots show the gaugings. The curve is plotted from the equation $x = 21.256\,y^2 + 0.8502\,y + 0.0004$, which is derived from the actual gaugings by the method of least squares.

THE UNIT OF MEASUREMENT USED.

In the tables which follow, the acre-foot is the unit of volume used. This is usually expressed by giving its equivalent in the depth to which the water used would have covered the surface irrigated. This unit was chosen because it is definite, and because it affords a convenient base for the comparison of quantities used in localities where the period of use was not the same.

It is usual in discussions of the duty of water to take the cubic foot

per second as the unit of quantity, and the period during which a crop requires water to bring it to maturity as the time during which the flow of that volume continues. Thus, when it is said that the duty of water is 60 or 80 acres to the cubic foot per second, the statement implies that the quantity of water used during the season had been measured and the average volume used during this season amounted to 1 cu. ft. per second for each 60 or 80 acres irrigated. In order to make this expression definite, it is necessary that the duration of the irrigation period be known; but this varies so widely in different localities, and in actual practice in the same locality, that it is difficult to compare the results obtained. In a number of discussions of this subject the assumed season for the Rocky Mountain regions has been taken as varying from 100 to 150 days. The records kept last year show, however, that water was used from the Gage Canal at Riverside, Cal., throughout the entire year, while the canal at Wheatland, Wyo., was operated only 60 days, and water was used in irrigation a shorter time. Since the practice varies so widely, any attempt at fixing an average period would be wholly arbitrary. Even under the same canal the length of the season has to be assumed, because no two irrigators use water for the same length of time. The length of the irrigating period at the several stations is shown graphically in Fig. 6. Nor does the assumption of a continuous flow accord with practice, because on many canals a system of rotation in the delivery of water is already in operation, and even where the contracts provide for a constant delivery it seldom happens that irrigators use water in this way. When, therefore, in practice, 20 miner's or statutory inches are used on an acre for a day, and none at all for the next twenty days, it is an error to discuss the duty as though a single inch had been used all the time. In nearly all the northern States fully three times as much water is used in July as in August. Hence, a discussion which deals with the delivery of water as though the use was uniform during this period is likely to lead to serious mistakes in practice.

By the use of the acre-foot as the unit of quantity all the arbitrary assumptions involved in the use of either the "inch" or the cubic foot per second are avoided, and its use is equally correct and convenient whether the supply comes from streams, wells or reservoirs, whether it is continuous or intermittent, and whether it ends in two months or extends throughout the entire twelve. The flow of 1 cu. ft. per second

DIAGRAM SHOWING DURATION OF IRRIGATION PERIOD ON MAIN CANALS INCLUDED IN INVESTIGATIONS.

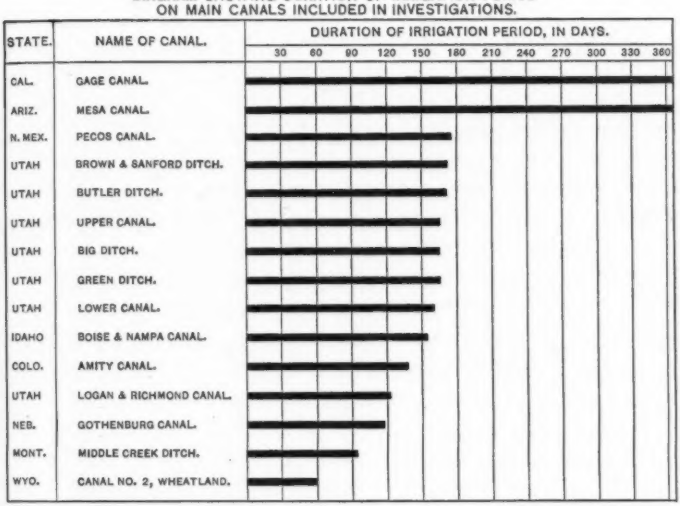

STATE.
NAME OF CANAL.
DURATION OF IRRIGATION PERIOD, IN DAYS.
30 60 90 120 150 180 210 240 270 300 330 360
CAL. GAGE CANAL.
ARIZ. MESA CANAL.
N. MEX. PECOS CANAL.
UTAH BROWN & SANFORD DITCH.
UTAH BUTLER DITCH.
UTAH UPPER CANAL.
UTAH BIG DITCH.
UTAH GREEN DITCH.
UTAH LOWER CANAL.
IDAHO BOISE & NAMPA CANAL.
COLO. AMITY CANAL.
UTAH LOGAN & RICHMOND CANAL.
NEB. GOTHENBURG CANAL.
MONT. MIDDLE CREEK DITCH.
WYO. CANAL NO. 2, WHEATLAND.

DIAGRAM SHOWING DURATION OF IRRIGATION ON FARMS WHERE WATER WAS MEASURED IN 1899.

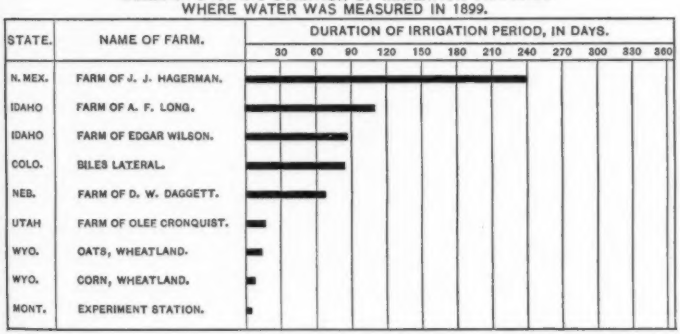

STATE.
NAME OF FARM.
DURATION OF IRRIGATION PERIOD, IN DAYS.
30 60 90 120 150 180 210 240 270 300 330 360
N. MEX. FARM OF J. J. HAGERMAN.
IDAHO FARM OF A. F. LONG.
IDAHO FARM OF EDGAR WILSON.
COLO. BILES LATERAL.
NEB. FARM OF D. W. DAGGETT.
UTAH FARM OF OLEE CRONQUIST.
WYO. OATS, WHEATLAND.
WYO. CORN, WHEATLAND.
MONT. EXPERIMENT STATION.

FIG. 6.

for 24 hours amounts to 1.98 acre-feet, so that the conversion of volumes from one unit to the other can be readily made.

Summary of Measurements of Duty of Water.

The measurements made by observers show that the duties obtained vary from less than 1 acre-foot of water per acre irrigated to over 15 acre-feet on an acre; but these wide and seemingly eccentric variations in the quantities used were the results of manifest causes. Where water was distributed through well-built ditches and used by careful irrigators, there was a surprisingly close agreement in results, even in widely separated localities. Table No. 1 will serve to illustrate this.

TABLE No. 1.—Quantity of Water Used, where Measurements Were Made on Small Canals or Short Laterals.

Location.	Depth of water used, in feet.
Cronquist Farm, Utah	2.60
Long Farm, Idaho	2.40
Gage Canal, Cal	2.24
Canal No. 2, Wyo	2.53
Vance Farm, Ariz	2.82
Biles Lateral, Colo	1.82
Middle Creek Ditch, Mont	2.10
Gothenburg Canal, Neb	2.47
Mean of all the above	2.37

An interesting comparison with the results in Table No. 1 is afforded by the mean of the duties on all the distributaries of the Ganges Canal for 1889-90, during the Khareef season, as reported in Buckley's "Irrigation Works in India." Here, the mean volume of water used in the irrigation of an acre of land was 121 970 cu. ft., equal to a depth of 2.8 ft. for the area irrigated.

Where the water was measured at the margin of the fields, there was a still higher duty than where measured at the heads of the laterals. Table No. 2 shows the duty obtained where all losses in distribution were eliminated, and nothing but the water actually spread over the fields was measured.

DIAGRAM SHOWING THE TIME OF IRRIGATION AND THE DEPTH OF WATER USED ON THE FARM OF OLEF CRONQUIST, LOGAN, UTAH.

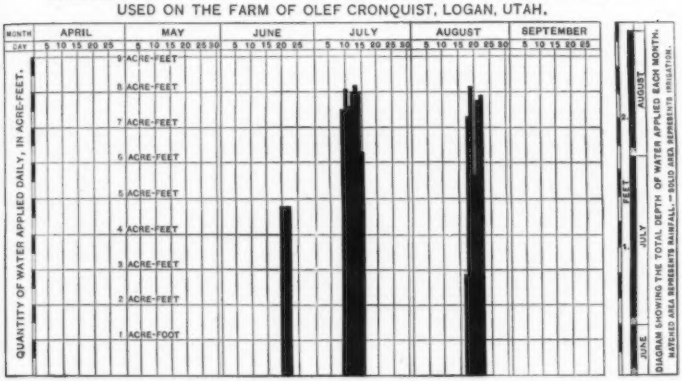


FIG. 7.

DIAGRAM SHOWING THE TIME OF IRRIGATION AND DEPTH OF WATER USED ON THE FARM OF A. F. LONG, NEAR NAMPA, IDAHO.

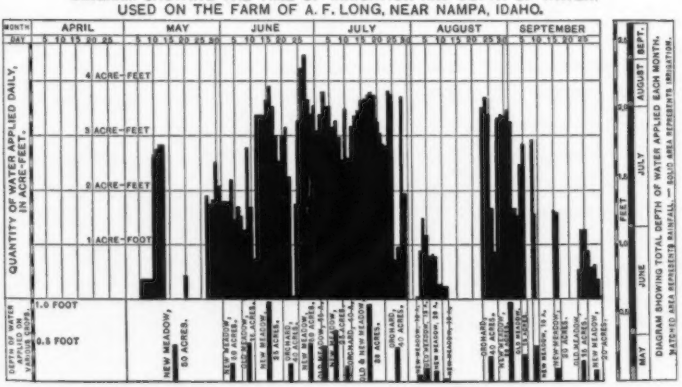


FIG. 8.

TABLE No. 2.—Quantity of Water Used, where Measurements Were Made at Margin of Field where Used.

Location.	Depth of water used, in feet.
J. Lateral, Wyo. (Oats)	1.55
J. Lateral, Wyo. (Corn)	0.70
Farm, Edgar Wilson, Idaho	1.48
Lowest Division, Gage Canal, Cal	1.78
Mean of measurements at Bozeman (Mont.), Experiment Station	1.20
Mean of all the above	1.34

The dates when water was applied, the length of the irrigation periods, the total acre-feet per day in use, the total depth of irrigation applied each month and the depth of rainfall for each month, are all shown graphically in Figs. 7, 8 and 9, for three of the stations named in Tables Nos. 1 and 2.

Losses by Seepage and Evaporation.

The duties given in the foregoing tables were obtained on laterals, or on canals where the losses in transit were not large, and on fields where the water was measured at the margin. They therefore represent, approximately, the volume utilized. In practice, however, the losses in canals, from percolation, leakage of flumes, evaporation, etc., are an important factor in fixing the average duty of water from a river or an extensive canal system. To determine this average duty, the volume should be measured at the headgate, and the number of acres it irrigates is the duty which canal managers have to consider in determining the area their works will irrigate. This duty is much lower than that obtained by measurements made on laterals or at the margins of the fields where used, the influence of the losses between the headgate and the heads of laterals being greater than has usually been supposed. Where canals cross gravel beds or gypsum deposits the results closely resemble trying to carry water in a sieve. Table No. 3 gives the depth of water used in irrigation, where the measurements were made at the canal headgates, and includes the loss from seepage and evaporation.

DIAGRAM SHOWING THE TIME OF IRRIGATION AND DEPTH OF WATER USED FROM THE GAGE CANAL IN DISTRICT NUMBER ONE, RIVERSIDE, CALIFORNIA.

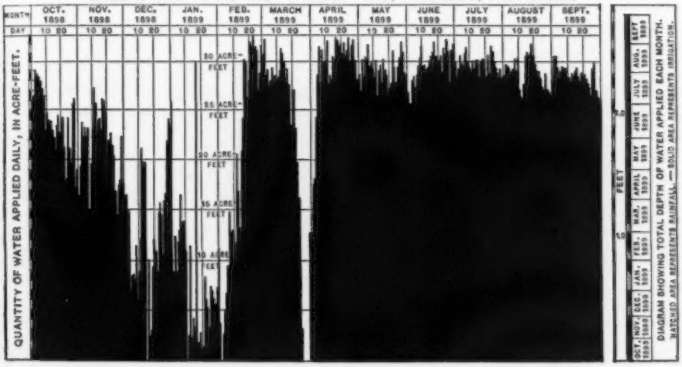


FIG. 9.

DIAGRAM SHOWING THE TIME OF IRRIGATION AND THE DEPTH OF WATER USED FROM THE BIG DITCH, SALT LAKE CITY, UTAH.

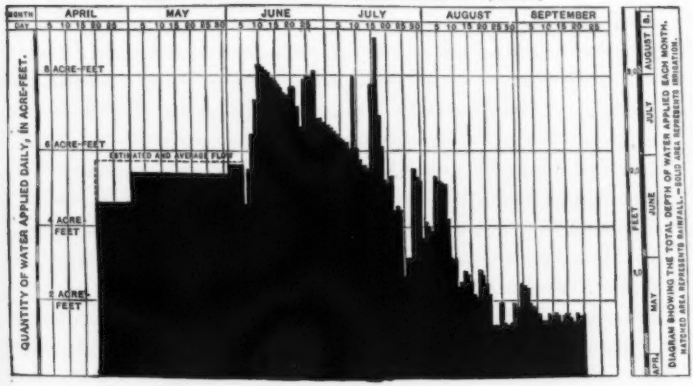


FIG. 10.

TABLE No. 3.—Depth of Water Used in Irrigation, when Losses in Main Canal are Included.

Name of Canal.	Depth of water used, in feet.
Pecos Canal, N. Mex	6.26
Mesa Canal, Ariz	3.81
Butler Ditch, Utah	6.24
Big Ditch, Utah	3.09
Upper Canal, Utah	6.30
Amity Canal, Colo	4.92
Rust Lateral, Idaho	5.06
Mean of all the above	5.10

For the Big Ditch, Salt Lake City, Utah, Fig. 10 shows when the water was applied and the total acre-feet applied per day, also the depth of irrigation water applied each month, and the rainfall for the same period.

A comparison of the duties in Table No. 3 with those obtained when the water was measured where used, will show that more than twice as much water was required where it was measured at the head-gate as where measured at the place of use. In other words, the losses in the canals from seepage and evaporation amount to more than half the entire supply. This is in accord with many of the measurements made on irrigation canals in India. Among those recorded in Buckley's "Irrigation Works in India" is one which shows that the irrigation of wheat under the Jamda Canal in Bombay required 5.6 acre-feet of water for each acre irrigated, where the water was measured at the head of the canal, but where the water was measured at the place of use it required, in two experiments, only 2.1 and 1.4 acre-feet, respectively, to irrigate an acre, the loss in the canal being more than 50 per cent. On the Hathmati Canal, in the same country, the loss from seepage and evaporation was 50 per cent. The losses in transit in our canals are much heavier than is the rule on the older canals of India, and are doubtless more general than they will be in this country when the banks of canals are older and when they are operated with greater regard for economy.

The reports of the special agents and observers in charge of these

measurements show that the losses from seepage and evaporation, where measured in 1899, were as follows:

Pecos Canal, N. Mex., loss	52.3%
Mesa Canal, Ariz., estimated loss	25.0%
Middle Creek Ditch, Mont., loss in 4 miles	22.0%
With probable loss for entire ditch of	35.0%
Jordan and Salt Lake Canal, Utah, loss	45.0%
Gage Canal, Cal., loss	0.5%

The Gage Canal, being cemented, the losses from seepage are practically nothing. As compared to losses varying from 25 to 75%, shown in other canals, the loss of only half of 1% in this canal has great significance. The water turned into the head would have served to cover the land irrigated to a depth of 2.24 ft., while the mean depth for the water delivered to irrigators' laterals was 2.11 ft., a loss of only 0.13 acre-foot per acre irrigated. Canals can only be cemented on earth, as is done in California, in localities where frosts in winter are not severe.

Relation of Losses in Transit to the Amounts of Appropriations.

This loss from canals has given rise to a number of perplexing questions regarding appropriations. The states of Nebraska, Wyoming and Idaho have fixed a maximum limit on the amount of water per acre which an appropriator can acquire. In two of these states no one is permitted to appropriate more than 1 cu. ft. per second for each 70 acres irrigated. This limitation has given rise to the question as to whether the water so appropriated is to be measured at the margin of the irrigated field or at the head of the canal. Appropriators have claimed that if measured at the headgate the losses in the canal will be so great that the amount delivered will be inadequate for their needs; while water commissioners have insisted that it will be practically impossible to measure each appropriation at the head of the user's lateral. Several contests over this matter have already arisen, and sooner or later an authoritative decision will have to be reached. In one instance all the water entering the canal is delivered at a point 11 miles below. Measurements were made to determine the loss in this distance, and it was found to vary from 18 to 36 per cent. It was urged that this loss was so great that the amount turned into the canal should be increased enough to compensate therefor, but the State authorities refused to

recognize this claim, on the ground that such a concession would put an end to the improvement of ditches, since the greater the loss, the larger the appropriation which would be secured, and that its practical effect would be to place a premium on poor construction and wasteful operating of canals.

Seepage Waters Reappearing in Springs and Ditches.

Much of the water which escapes from canals finds its way to the surface below in the form of springs in what were originally dry ravines. Irrigators have filed on these springs, and secured thereby an ample water supply without having to pay the canal company which furnishes it anything for operating expenses or for the purchase of a water right. On the South Platte River alone there are over 400 of these filings on seepage waters. The report of the State Engineer of Colorado for 1898 shows that 5 000 acres in the Poudre Valley were irrigated with seepage water in that year. In a number of instances canal companies have sought to establish a title to the water of these springs and to collect for its transportation from their users; but the decisions of the courts in these cases have been conflicting, and no settled policy has as yet been established.

In some cases, where slopes are crossed by several canals, the lowest one frequently is benefited rather than injured by filtration, as it intercepts the water lost above. In one instance, where it is known that a large volume of seepage water is escaping from high-line canals, a ditch has been cut parallel with the river bank, but some distance away from it, to intercept this percolating supply. This has led to litigation to determine whether or not this is an interference with the rights of prior appropriators below on the main stream.

The percolating waters from canals and irrigated fields materially increase the water supply of western rivers. Measurements of this return or seepage water have shown that this reaches in many instances 30% of the original volume. In some cases it exceeds the original supply.

Influence of Fluctuations in Supply on the Duty Obtained.

A low duty does not of necessity indicate a wasteful or unskilful use of water. An illustration of this is found on streams which furnish more water than can be used during the flood season, but where the

period of plenty is followed by an equally assured period of drought. Irrigators have learned to provide against the latter by pouring on their land all the water it will hold while it can be had. By thus saturating the subsoil they store up a reserve supply which plants draw upon when the ditches fail. The report of one special agent deals with this practice, and a study of the flow of water in the Mesa Canal shows how marked is the scarcity during the hottest part of the year, and that at the time when the most water would be used if it could be had, less was actually used than at any other time in the season. That it is better to waste water on the land when there is a surplus, than to let it escape down the river and have crops burn later in the season, is beyond question, but the results of such irrigation are not nearly so satisfactory as they would be if this flood supply could be stored in reservoirs and be available for use when needed. Mr. Code's report shows clearly the necessity of reservoirs in localities like the Salt River Valley. They are needed to store the floods which now run to waste. They are needed to enable farmers to use water when crops demand moisture, and to relieve them from the alternating floods and drouths which dependence on the stream alone renders inevitable.

The Difference Between the Assumed Duty in Canal Contracts and the Duty Found by the Year's Measurements.

A comparison of the results of the year's measurements with the duty of water assumed in many important water-right contracts is interesting as showing their agreement or departure from actual practice. The quantity of water agreed to be furnished by a number of canal companies is as follows:

Arizona.

Arizona Water Company sells perpetual water rights, for 0.83⅓ cu. ft. per second to be used on not to exceed 80 acres. This gives a duty of a little less than 100 acres per cubic foot per second, or a depth of 7.5 ft. on the land irrigated.

Consolidated Canal Company sells perpetual water rights for not to exceed ½ miner's inch per acre. This gives a duty of 120 acres per cubic foot per second, or a depth of 6 ft.

Rio Verde Canal Company sells water by quantity, agreeing to furnish sufficient water to cover land to a depth of 2 ft. if it is called for, and more at the option of the company.

California.

Gage Canal allows 1 in. to 5 acres, or 1 cu. ft. per second to 250 acres. This water is not delivered in continuous flow, but in large streams for short periods, at the convenience of the consumer. This flow gives a depth of 2.89 ft.

Colorado.

Larimer County Ditch sells water rights for $\frac{1}{60}$ of the capacity of the ditch, without specifying how much land is to be irrigated.

New Loveland and Greeley Irrigation and Land Company sells one water right for each 80 acres, allowing a flow of 1.44 cu. ft. per second. The Colorado law compels companies to furnish water from April 1st to November 1st. For that length of season 1.44 cu. ft. per second would cover 80 acres to a depth of 5.3 ft.

Platte Valley Irrigation Company sells a water right for each 80 acres, allowing a flow of 1.44 cu. ft. per second, or a depth of 5.3 ft.

Fort Morgan Land and Canal Company sells a water right for each 80 acres, allowing a flow of not to exceed 1.44 cu. ft. per second for the irrigating season, or a depth of 5.3 ft.

Arkansas River Land, Reservoir and Canal Company sells a water right for each 80 acres, allowing a flow of not to exceed 1.44 cu. ft. per second, or a depth of 5.3 ft.

Dolores No. 2 Land and Canal Company sells water by the cubic foot per second, without limiting the consumer as to the area which he may irrigate.

Idaho.

Phyllis Canal contracts provide that the amount of water delivered shall not at any time exceed an amount equivalent to 1 cu. ft. per second for 50 acres, and that the total maximum quantity allowed shall not exceed 2 ft. in depth on the land irrigated; since 1899, will sell water by the cubic foot per second, with no limitations as to the area to be irrigated.

Boise and Nampa Canal, until 1899, delivered water at the rate of 1 miner's inch to the acre, but not to exceed 3 ft. in depth on the land irrigated. Since 1899, sells water by the cubic foot per second, with no limitations as to the area to be irrigated.

Montana.

Minnesota and Montana Land and Improvement Company sells water by the miner's inch without regard to the area to be irrigated. For the season of 1899 the farmers under this company's canal ordered, on an average, 1 miner's inch for 3.77 acres, showing a duty of about 150 acres per cubic foot per second.

Nebraska.

North Platte Irrigation and Land Company sells water rights for 1.44 cu. ft. per second, and prescribes land on which it shall be used.

Interstate Canal and Water Supply Company (Wyoming and Nebraska) agrees to furnish 1 in. per acre, or 1 cu. ft. per second for 50 acres. The legal season in Nebraska is 200 days—from April 15th to November 1st. One cu. ft. per second will cover 50 acres to a depth of 7.9 ft. in that time.

New Mexico.

Pecos Irrigation and Improvement Company water-right contracts provide for the delivery of 43 560 cu. ft. of water per acre, sufficient to cover the land to a depth of 1 ft., delivered at such times and in such quantities as may be necessary for the proper irrigation of crops.

Texas.

T. C. Purdy's water-right contracts call for the delivery of 43 560 cu. ft. per acre, to be delivered in not more than five irrigations per annum.

Washington.

Yakima Investment Company contracts to deliver not to exceed 1 cu. ft. per second per 160 acres, from April 1st to October 31st. This gives a depth of 2.65 ft.

Wyoming.

Wyoming Development Company sells water rights, giving the right to part of the total flow of canal.

Fetterman Canal Company sells a water right for each 8 acres, allowing a flow of $\frac{1}{10}$ cu. ft. per second. Wyoming canals do not ordinarily run more than 60 days. In that time this flow would give a depth of 1.46 ft.

Cody Canal shares represent water for 40 acres, and the quantity delivered is not to exceed $\frac{1}{4}$ cu. ft. per second. This gives a depth of 1.46 ft. in 60 days.

Need of Continuing the Investigation.

The investigations of the past year did not deal with all the factors which influence the duty of water, because time did not permit of their study. For these reasons, the necessity for storage reservoirs has been left for subsequent study and discussion. The subject is

of commanding importance, because it cannot be considered apart from the fundamental question of who is to own or control the stored water, and likewise the stream from which it is taken or along which it is impounded. Sooner than is generally realized, the public or private ownership of western rivers is destined to be one of the great social and industrial questions of this country. Their waters are worth more than the land, public or private, through which they flow, and the manner of their disposal will do more to shape western civilization and promote or retard western development than all other causes combined. The study of the duty of water is a study of the farmer's needs, and it is hoped that the presentation of these needs will tend to promote the creation of an irrigation system which will make the supplying of his necessities of first importance, and be a matter of just pride to the nation.

TABLE No. 4—SUMMARY OF MEASUREMENTS OF DUTY OF WATER, 1899.

Station.	Period during which water was used.	Rainfall.	Evaporation.	General Duty.		Special Measurements of Duty.			Remarks.
				Depth of irrigation.	Depth of irrigation and rainfall.	Location.	Depth of irrigation.	Depth of irrigation and rainfall.	
		Feet.	Feet.	Feet.	Feet.		Feet.	Feet.	
Carlsbad, N. Mex.—									
Pecos Canal	Entire year	*0.31	4.55	6.26	6.57	Hagerman Farm	15.44	15.75	Measurements carried on from April to October.
Mesa, Ariz. (Mesa Canal)—									
1896	"	0.78	.....	5.91	6.69				
1897	"	1.04	.....	5.55	6.59				
1898	"	0.57	.....	5.01	5.58				
1899	"	0.39	.....	3.81	4.20				
Riverside, Cal.—									
Gage Canal	"	0.47	.....	2.24	2.71	District No. 1	2.32	2.79	
						District No. 2	2.23	2.70	
						District No. 3	1.78	2.25	
Salt Lake City, Utah—									
Butler Ditch	April-September	0.49	.....	6.24	6.73				
Brown & Sanford Ditch	"	0.49	.....	5.32	5.81				
Upper Canal	"	0.49	.....	6.30	6.79				
Green Ditch	"	0.49	.....	4.52	5.01				
Lower Canal	"	0.49	.....	2.83	3.32				
Big Ditch	"	0.49	.....	3.09	3.58				
Logan, Utah—									
Logan and Richmond Canal	June-September	0.27	3.27	3.59	3.86	Cronquist Farm	2.60	2.87	
Lamar, Colo.—									
Amity Canal	March-September	0.91	.....	4.92	5.83	‡ Biles Lateral	1.82	2.50	
Gothenburg, Neb.—									
Gothenburg Canal	June 7th-September 30th	1.26	.....	2.57	3.83	§ Daggett Farm	4.24	5.50	
Wheatland, Wyo.—									
Canal No. 2	June-August	0.37	1.26	2.53	2.90	J. Lateral	.....	.....	Evaporation at Laramie, Wyo.
						Oats	1.55	1.92	
Boise, Idaho—						Corn	0.70	1.07	
Boise and Nampa Canal	May-September	0.22	.....	.....	.....	Rust Lateral	5.06	5.28	
						A. F. Long Farm	2.40	2.62	Rainfall at Boise.
Bozeman, Mont.—						Wilson Orchard	1.48	1.70	" "
Middle Creek Ditch	June 16th-Sept. 16th	0.42	†1.74	2.10	2.52	Bozeman Exp. Farm			
						Clover	1.02	1.46	Rainfall 0.44 ft.
						Pease	1.10	1.51	" 0.41 "
						Grain	1.98	2.40	" 0.42 "
						Barley	0.98	1.39	" 0.41 "
						Oats	1.53	1.91	" 0.38 "
						"	1.34	1.70	" 0.36 "
						"	2.16	2.52	" 0.36 "
						"	1.28	1.72	" 0.44 "

*May 1st to November 11th, 1899. † Evaporation from July 6th to September 30th. ‡ Water used under Biles Lateral, April-September. Rainfall at Holly, Colo., 0.68 ft. § Rainfall, April to September. Water used after harvest.

DISCUSSION.

Mr Merriman. MANSFIELD MERRIMAN, M. Am. Soc. C. E.—In this paper the word "duty" seems to have been used in two senses which are not exactly the same. It is said that the number of acres irrigated by 1 cu. ft. per second is the duty of water. That appears to be an excellent definition, and one that agrees with the use of the word duty in other branches of engineering; but when it is said that 1 acre of land requires so many acre-feet of water to irrigate it, this is not properly the duty of water, but rather a reciprocal of duty. The speaker has found that in presenting engineering matters to students it is extremely important to have the units very clearly and closely defined, and although this word duty is perhaps the least important of all the units, the speaker believes that it may deserve the remark he has made concerning it.

In this connection, the speaker was glad to note that in the publications of this Society on hydraulic matters the terms "second-foot" or "foot-second," as some people say, are not used. These terms lead to confusion, while "cubic feet per second," which should be always used, is clearly understood by everybody. There are many hydraulic engineers, particularly in the Government employ, who always say "second-feet" in designating the discharge of water, which is contrary to the principles of formation of compound units. In such a unit, as a foot-pound, or ton-mile, the meaning of the hyphen is that the two simple units are multiplied together; and in the term "second-feet," it might be natural to think that the number of seconds should be multiplied by the number of feet, which would be absurd. On the other hand the word "per" means division; for instance, "cubic feet per second," means the total number of cubic feet divided by the total number of seconds, and is therefore clearly understood. The term "acre-foot" is an excellent compound unit, formed according to correct principles.

Mr. Hering. RUDOLPH HERING, Vice-President, Am. Soc. C. E.—It seems strange that up to the present time the relationship of irrigation and drainage to agriculture has received so little attention. It is only quite recently that proper observations have been made as to the quantity of water which various crops require at different times. The agricultural experiment stations in the United States have begun to make some observations on that subject, and similar stations in Europe are doing the same. Yet it is hardly possible to get reliable information, except from a few isolated points and regarding a few plants. For instance, in this country, the agricultural station at Madison, Wis., is the only one known to the speaker at which the amount of water required

during the different months by a certain crop has been determined, and they have there experimented with scarcely a dozen crops. Mr. Hering.

The speaker believes that it is very important for the agricultural, irrigation or drainage engineer, to know just what amount of water the different crops need and when they need it, particularly in those sections of our country where there is scarcity of water. It is known that during different stages of growth plants need different quantities of water. For instance, at first, during the period of germination, nearly all plants need more than immediately after they have started to grow. Then, they again need a larger quantity, in fact, the most liberal irrigation, when passing through the flowering stage, and the least quantity during fruiting and maturity, when too much water becomes rather injurious.

As this subject is one which the engineer in this country has to meet occasionally, the speaker, when in Europe this summer, made some inquiries thereon, but found a remarkable dearth of experience there also; yet every station is at work trying to get results on the subject.

There is a correlative subject upon which we also have scarcely any data: Where there is water in the ground which is to serve the roots, the question sometimes arises, how far can the ground-water stand below the roots in order that these may still receive sufficient moisture? In our immediate neighborhood there are at this day suits threatened for several hundred thousand dollars which depend upon that very fact, as to the relation of the quantity of water needed by certain crops, the capillarity of the soil, and the level of the ground-water. This is a question which we, as engineers, will eventually have to face. As yet, there is but little information on the subject, and it is very gratifying indeed to see that certain Government officers at the agricultural stations, and engineers abroad, are now studying this matter which, in our country, in one way and another, represents a great deal of money to agriculturists.

A. D. Foote, M. Am. Soc. C. E. (by letter).—Professor Merriman's remarks on the erroneous use of the term "second-foot," or "foot-second," are most heartily concurred in by the writer. It is hoped that the members of the United States Geological Survey may read it and take heed. They gave us the excellent term "acre-foot," Major Powell first using it; they also gave us the term "Nilometer" (Major Dutton), which is perhaps the most misleading name ever applied to a bit of clockwork. The Nilometer is a pillar on the banks of the Nile which has been watched by the Egyptians since beyond the time of any human record, telling them each year of disaster, plenty or famine as the water rose to the marks upon its sides. Mr. Foote

There can be no other Nilometer, and to apply its name to the weir register standing on the bank of the "Old Woman's Fork," in

Mr. Foote. Wyoming, is certainly something more than an anachronism. The "Old Woman's Forkometer" would be an analogous term, perhaps, and much more appropriate.

A matter worth recording in connection with Mr. Mead's weir registers, rather than as a comparison or criticism, is the following description of a register designed by Mr. G. F. Sherman, Assistant Superintendent of the North Star Mines Company. The main differences from ordinary weir registers are that the clockwork regulates the movement of the paper by holding it back instead of carrying it, and the rapid motion of the paper gives opportunity for recording very frequent variations; also, the roller marks lines on the paper so as to give an accurate and continuous scale of heights in perfect agreement with the pencil.

The Empire Mine, in Grass Valley, obtains its power chiefly from water delivered at the mine, by the North Star Mines Company, under a head of about 400 ft., which is applied to several impulse wheels, each running its own machine. In the routine work of the mine the use of water is extremely variable, making it necessary to have some indisputable record of its fluctuations in order to determine the actual flow.

The weir register here described, was designed for this purpose early in 1899, and made in the machine shop at the North Star Mine. It consists of two brass rolls carrying a strip of paper, wound from one on to the other, and which passes through a pair of governing rolls between them. It is driven by a weighted cord, and its speed is regulated by a clock movement geared to one of the governing rolls. The machine is placed over a water chamber connected by a pipe to the weir box. A rod attached to a copper float rises and falls with the variations in height of the water on the weir. It is guided at the top by an easy-fitting slotted bracket, and at the bottom by a rod which plays in a pipe passing through the float.

The pencil it carries is pressed against the paper by a light spring contained in the bracket. A fifth roll, not absolutely essential, supports the paper against the pencil, and keeps it smooth and in a fixed position, which would not be the case if it worked against one of the other rolls gradually increasing or diminishing in diameter. The pencil marks the paper before it passes over the governing rolls in order to avoid catching in the grooves in the paper made by them. The float is large enough to require a weight of about 2 lbs. to sink it $\frac{1}{8}$ in. below its proper depth of flotation.

The other details of construction relate chiefly to the difficulties of constructing a true light-running machine with the facilities at hand. In order to allow for a slight eccentricity in the governing rolls, as well as the varying thickness of the paper used, one of the rolls revolves in sliding boxes which are pressed toward the other by

springs with adjustable tension. No clock, with power enough to make any impression upon the speed of the paper, even when most of the work was done by the weight, could be obtained, but it was found that a clock could stand a heavy drag, tending to accelerate it, and still run regularly; therefore, enough weight is put on the cord to run it too fast at all times, and the clock holds it back to a uniform rate. The paper moves 30.5 ins. per day, exposing at any time the record for the previous 12 hours. The record is removed once or twice a month, but the supply roll carries sufficient paper to run for 6 months. Mr. Foote.

The weir is 3 ft. long, rectangular, with suppressed end contractions, and is not expected to measure a flow of more than 10 cu. ft. per second.

The daily average height is determined by measuring the area above a known height and below the record line, with a planimeter, and dividing by the length. To assist in getting the areas, and also in estimating the flow at any time, ridges are turned on one of the governing rolls, which mark the paper in lines 0.05 ft. apart, the lowest line corresponding to zero on the weir. This method of obtaining average heights from areas is, of course, not quite correct, but is a rapid way of getting a result accurate enough for practical purposes.

ELWOOD MEAD, M. Am. Soc. C. E. (by letter).—The cubic foot per second is not a satisfactory unit in studies or discussions of the duty of water. On the contrary, it is nearly always misleading. It assumes that water is used continuously and at a uniform rate of flow, while, in fact, it seldom is. In the studies made at the Experiment Stations of the United States Department of Agriculture last year there were some farms on which the water was only used for seven days; on others for more than three hundred. In some cases it would be used only a few hours at a time, with alternating periods of non-use or partial use. Hence, the discussion of the duty of a cubic foot per second of water would have been wholly theoretical. On the other hand, a discussion of the duty of an acre-foot involves no misleading or purely arbitrary assumptions. It is just as definite a unit as the cubic foot per second, and has the advantage of eliminating the element of time and rate of delivery in the comparison of results. Hence, the acre-foot is used in describing these investigations. Sometimes it would seem to be clearer to speak of the depth to which the water used would cover the land. Where this is done it is not the duty of the acre-foot, but the reciprocal of the duty, which is referred to, as Mr. Merriman has pointed out, and that explanation is made in the first report of the investigations, but was overlooked in the paper. So understood, no misconception can arise. Mr. Mead.

The relationship of irrigation and drainage to agriculture has, as

Mr. Mead. Mr. Hering points out, been strangely overlooked in this country. Since taking charge of these investigations for the Office of Experiment Stations the writer has been doing all he could to promote the study of agricultural engineering in the Agricultural Colleges of the arid region, but finds it difficult, at times, to make the authorities understand that this subject comes properly within the province of these schools, and that they are different from schools of hydraulic engineering. The moisture studies, referred to by Mr. Hering, have already been inaugurated in California, and, from the facts gathered, it is believed that they are destined to greatly benefit the agriculture of that state. In the San Joaquin and Sacramento Valleys, where both temperature and evaporation are excessive, certain crops are successfully grown with a rainfall which varies from 6 to 16 ins. How this is accomplished has long been an enigma to the writer, but one explanation seems to be that much of the water needed by plants is pumped up by the roots from several feet below the surface, where the soil is not moistened by rains but by the water which percolates from streams.